Ship-based and satellite remote sensing cloud retrievals consistency and the quantification of aerosol-cloud interactions

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1. Introduction

- The northeast (NE) Pacific has been identified as one of the subtropical cloud regimes where microphysical variability driven by aerosols can strongly modify the albedo of the cloud deck [e.g., Painemal and Minnis, 2012]. Satellite-derived cloud droplet number concentration in this region has a notorious westward decrease (Fig. 1).
- The deployment of the second AMF on the container ship, Horizon Spirit, during MAGIC campaign presents a unique opportunity to investigate the aerosol variability and cloud-aerosol interactions in marine clouds [Lewis and Teixeira, 2015].
- We evaluate the consistency among different remotely sensed cloud and aerosol properties and analyze their applicability to the quantification of aerosol-cloud interactions during MAGIC.

2. Dataset

Ship-based observations
Liquid water path from a 3-channel microwave radiometer [Cadeddu et al., 2013]. Cloud optical thickness (τ) and effective radius (r_e) from a sun-photometer [Chiu et al., 2011].
Aerosols: CCN probe, aerosol size distribution from an Ultra-High Sensitivity Aerosol Spectrometer (UHSSA), aerosol scattering and absorption coefficient from a nephelometer, and a particle soot absorption photometer (PSAP), aerosol backscatter from a high spectral resolution lidar (HSRL).

Satellite data
τ, r_e, and LWP from the MODerate resolution Imaging Spectroradiometer (MODIS) and geostationary GOES-15 Imager using CERES edition 4 algorithms. MODIS 1km and GOES 4km pixel resolution averaged to a 20 km grid.

3. Results

3.1. Ship-based vs satellite cloud properties
- Collocated satellite LWP and τ and r_e well with their hourly-mean ship-based counterparts (Fig. 2a and b, respectively).
- Cloud droplet number concentration (N_d) assuming adiabaticity [e.g., Painemal and Zuidema, 2013]. This allows to calculate N_d in terms of (LWP, τ), or (LWP, r_e).
- Satellite vs ship-based comparison is best when N_d is derived from τ and LWP. τ is typically a more robust ground-based retrieval than r_e [e.g. Chiu et al. 2012].

3.2. Aerosol proxies
We investigate whether aerosol accumulation mode (N_d, UHSSA), dry scattering (σ_scatt, nephelometer), and extinction coefficients (σ_ext, nephelometer+PSAP) can be used as CCN proxies (0.4% of supersaturation).
- Accumulation mode reproduces the CCN variability (Fig. 3a).
- σ_scatt and σ_ext correlate well with CCN (r=0.9), with a modest effect of absorption (Fig. 3b-c).
- York linear fit calculations assuming varying errors (δ) in σ_scatt and σ_ext and a fixed error in CCN of 10% yield logarithmic slopes between 0.62-0.78, consistent with Shinozuka et al. [2015].

3.3. Aerosol-Cloud co-variability
We used a simple metric for quantifying aerosol cloud interactions (ACI): \( ACI = \frac{\partial \ln (N_d)}{\partial \ln (a)} \), with a denoting surface observations of CCN or accumulation mode concentration (N_d).

Satellite-based N_d vs ship-based CCN
Ship-based N_d vs ship-based CCN
Ship-based N_d vs ship-based N_a

3.4. Aerosol vertical structure: preliminary HSRL analysis
- HSRL particle backscatter was used to investigate the aerosol vertical structure during July 2013.
- Coupled and decoupled samples: cloud base height and lifting condensation level difference < 200 m and > 400, respectively.
- Decoupled boundary layers are deeper and backscatter decreases near the cloud base for the decoupled profile (Fig. 5a).
- Strong correlations between backscatter at 150 m and those from levels below 400 m. Reduced correlation near the cloud base for the decoupled profile (Fig. 5a).
- Red and black are coupled and decoupled cases, respectively.

4. Concluding Remarks
- Agreement between satellite and ship-based cloud properties yield consistent N_d-CCN relationship.
- Accumulation mode aerosols and extinction coefficients are adequate CCN proxies over this region. Extinction-CCN slope r=1.0.
- Strong aerosol-cloud interactions consistent with aircraft observations in other marine low clouds regimes.
- Results point to deficiencies in previous satellite-based estimates.
- Information about the aerosol vertical structure might be important in deep (decoupled) boundary layers.

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References:
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